10/590354
IAP12 Rec'd PCT/PTO 23 AUG 2006

SPECIFICATION

CASTING PROCESS

Field of the Invention

This invention relates to a casting process, more particularly, to a casting process that is capable of substituting for the conventional shell mold process and capable of readily removing a mold.

Background of the Invention

As one example of conventional light metal casting processes, a shell mold process is known as disclosed in Japanese Patent Early-Publication No. 5-261478. The shell mold process employs a binder that includes a phenol-formaldehyde resin. Molding sand that is coated with such a binder is charged into a heated mold using a blowing introducing process. The coating binder of the charged molding sand is then hardened by the heat transferred from the mold.

In the shell mold process, however, a core mold that is poured and molded has a higher hardness. This needs a core-knockout process to apply greater impact forces to the core mold to collapse or crush it to remove it from a cast article. To carry out the core-knockout process, the cast article should be sufficiently cooled before it is heat treated. As much as 70-80% of the sand grains can be removed from the cast article when the relatively high impact forces of not less than 1MPa at an operating frequency as high as 10Hz or more are applied for 10 seconds or more. Consequently, the resulting collapsed or crushed core mold causes the residues of its sand grains (core-sand grains) or crushed rocks to remain in the cast article during the heat treatment of it and the following processes. Therefore, the process of removing the residues may be needed once again. To recycle and use recovered residues of the

collapsed core mold from the cast article, a roasting process is generally required to achieve this purpose.

In the shell mold process, the binder generates volatile gases when it is to be hardened by the heat transferred from the mold. The volatile gases involve unpleasant odors. Particularly, the phenol-formaldehyde, phenol, and ammonium gases impose a biohazard for humans.

Accordingly, it is desirable to provide a casting process that can be substituted for the conventional shell mold process, and can readily remove a mold, while it reduces the voltaic gases.

Disclosures of the Invention

As used herein, the term "an aggregate granular material" means that it comprises one or more of silica, zircon, sand, olivine sand, chromite sand, mullite, artificial sand, and so forth.

As used herein, the term "after a molten metal is solidified" or "the solidified molten metal" refers to the molten metal being solidified and hardened. The temperatures at which the molten metal can be solidified and hardened are various, and depend on the kinds of the processes and the materials of the molten metal.

As used herein, the term "during a cooling process of a cast article" refers to the period to cool the cast article to lower the temperature until the cast article is cooled enough to cause no deformation of it when it is removed from the completed mold. For example, in the T6 treatment for an aluminum alloy, the term "during a cooling process of the cast article" refers to the period to cool the cast article lower than about the 520 ℃ used for a typical solution treatment, but higher than the conventional cooling range from 70 ℃ to 111 ℃, such as the period to cool the cast article at temperatures down to 300 ℃.

One aspect of the present invention provides a casting process. The process comprises the steps of:

mixing one or more kind of aggregate granular material, one or more kind of a water-soluble binder, and water to form a mixture of the aggregate granular material, and stirring the mixture to cause it to foam;

charging the foamed mixture into a molding space, and evaporating the moisture within the charged mixture to harden the charged mixture to mold a mold with the hardened mixture;

assembling at least one mold that is cast in the hardened mixture with the mating mold to form a completed mold;

pouring molten metal into the completed mold;

removing the completed mold from a cast article that is composed of the solidified molten metal during a process of cooling the cast article after the molten metal is solidified; and

applying a heat treatment to the cast article.

Preferably, the mold that is cast in the hardened mixture is a core mold. In this case, a mating mold, i.e., a master mold, may be a metal mold or a sand mold.

As used herein, the term “a complete mold” refers to an assembly that is assembled from the master mold with at least one molding mold, i.e., the core mold. Such an assembly refers to a mold for which the molten metal can be poured. Accordingly, the complete mold may include any element required for the pouring process, as well as the master mold and the core mold.

The casting process of the present invention may further comprise the steps of returning the aggregate granular material, and recovering the returned aggregate granular material. The returned and recovered aggregate granular material is preferably recycled and used for molding a mold.

In one embodiment of the present invention, the steps of returning and recovering the aggregate granular material are mechanical recovering processes.

The cast article may be cast in an aluminum alloy, a magnesium alloy, a copper alloy, and so forth.

The heat treatment may be the T6 treatment or the T7 treatment.

In one embodiment of the present invention the step of removing the completed mold from the cast article is to shake the completed mold. For example, it includes impact forces of less than 1MPa at an operating frequency at less than 30Hz being applied in the completed mold for less than 30 seconds, within from 5 to 20 minutes after the molten metal is poured.

Another aspect of the present invention provides a casting process that comprises the steps of:

mixing one or more kind of aggregate granular material, one or more kind of a water-soluble binder, and water to form a mixture of the aggregate granular material, and stirring the mixture to cause it to foam;

charging the foamed mixture into a molding space, and evaporating the moisture within the charged mixture to harden the charged mixture to mold a core mold with the hardened mixture;

assembling at least one core mold that is cast in the hardened mixture with a metal mold to form a completed mold;

pouring a molten aluminum alloy into the completed mold;

removing the core mold from a cast article that is composed of the solidified molten aluminum alloy during a process of cooling the cast article after the molten metal is solidified; and

applying the T6 or T7 heat treatment to the cast article that is cast in the aluminum alloy.

One or more kind of the water-soluble binder is at least a polyvinyl alcohol or its derivative, or at least a starch or its derivative.

Brief Descriptions of the Drawings

Fig. 1 shows a flowchart of the casting process of the present invention.

Fig. 2 shows a flowchart of the conventional casting process based on the prior-art shell molding process.

Fig. 3 is a representation by a graph of the relationships between the temperatures of a cast and the times during the steps to remove a completed mold from the cast article and to apply a heat treatment to the cast article.

Fig. 4 is representation similar to Fig. 3, but for the corresponding steps of the conventional casting processes based on the prior-art shell molding process.

Preferred Embodiments of the Invention

Fig. 1 is a flowchart that schematically shows the steps of the casting process of the present invention. The principles of the casting process of the present invention will now be described in line with the flowchart of Fig. 1.

In a first step, one or more kind of aggregate granular material, one or more kind of a water-soluble binder, and water are mixed to form a mixture of the aggregate granular material. The resulting mixture is then stirred to cause it to foam (the first or preparing step 1).

In a second step, the foamed mixture obtained in the first step is charged into a molding space. The moisture within the charged mixture is then evaporated to harden the charged mixture to mold a mold with the hardened mixture, i.e., the aggregate granular material (the second or molding step 2).

In a third step, at least one mold (a core mold) that is cast in the hardened mixture is assembled with a mating mold (a master mold) to form a completed mold (the third or assembling step 3).

In a fourth step, a molten metal is poured into the completed mold (the fourth or pouring step 4).

In a fifth step, the core mold is removed ("core out") from a cast article that is composed of the solidified molten metal to disassemble the completed mold during a process of cooling the cast article after the molten metal is solidified (the fifth or disassembling step 5).

In a sixth step, a heat treatment is applied to the cast article (the sixth or heat treatment step 6). The resulting completed cast article is thus produced.

Now the steps of Fig. 1 will be described in more detail.

In the preparing step 1, the aggregate granular material comprises one or more materials made of silica, zircon, sand, olivine sand, chromite sand, mullite, artificial sand, and so forth.

A desirable water-soluble binder has water-solubility at room temperature. The water-soluble binder having the water-solubility at room temperature can be formed into the aggregate granular material without heating. This can save the energy and time required for heating the binder and the aggregate granular material that would otherwise be required. This advantage of the present invention is significantly contrasted with the prior-art production of coated sand in the conventional shell molding process.

As nonlimiting examples, a suitable water-soluble binder is a polyvinyl alcohol or its derivative, or a starch or its derivative, or both. Because the water-soluble binder can be readily evaporated or dissolved, the core mold can be readily removed from the cast article in which the molten metal has been solidified in the fifth disassembling step 5. The aggregate granular material preferably contains the water-soluble binder from 0.1 to 5.0 wt% based on the total weight of the aggregate granular material.

One or more kind of the water-soluble binder and one or more kind of the aggregate granular material and water are mixed to form a mixture of the aggregate granular material. The mixture of the aggregate granular material is stirred to cause it to foam and thus it is formed as a whipped cream mixture.

In the molding step 2, the foamed mixture is charged into the molding space, and the moisture within the charged mixture is then evaporated to harden the charged mixture to mold a core mold. This core mold has a hollow structure due to the foam within the aggregate granular material. The hollow core mold has a porosity of 3 to 60 %. For example, if the hollow core mold is about 40 mm in thickness, more than 50% of a water-soluble binder is aggregated in the surface layer between the surface of the core mold and a depth of 10 mm therefrom. In the hollowed core mold composed of the foamed aggregate granular material, the distribution of the foam in the aggregate granular material and the moisture content of the binder are concentrated at the center portion of the core mold. After the moisture is evaporated, the center portion of the core mold has thus a low density of the charged aggregate granular material.

In the assembled step 3, at least one molded core mold that is cast in the hardened aggregate granular material is assembled with a master mold (a mating mold) to form a completed mold. The master mold may be a metal mold or a sand mold that is composed of, e.g., the aggregate granular material. In this embodiment, the master mold is a metal mold, and the casting process is a low-pressure casting. If the master mold is a metal mold, the casting process of the present invention is not limited to the low-pressure casting, but may be applied to a back-pressure casting, a die-casting, or a gravitational casting for casting the metal mold and so forth.

In the pouring step 4, the embodiment employs, without limitation, an aluminum alloy as the molten metal to be poured into the completed mold. As the molten metal, other materials, including a light metal alloy or a non-ferrous alloy (e.g., a magnesium alloy or a copper alloy) may be used. Alternatively, a cast iron, a cast steel, or an iron metal alloy may be used. If the iron metal alloy is used as the molten metal, a mold wash or a facing material may be desirably applied on the core mold.

In the disassembling step 5, the core mold is removed from the cast article during the periods for a process to cool the cast article or the period to cool the cast article and lower the temperature until the cast article is cooled enough to cause no deformation of it when it is removed from the completed mold. If the material of the molten metal in the fourth or pouring step 4 is an aluminum alloy, the term “during the periods of a cooling process of the cast article” refers to the period to cool the cast article lower than about the 520 ℃ used in the solution treatment, but higher than the conventional cooling range from 70 to 111 ℃, such as the period to cool the cast article at a temperatures down to 300 ℃.

In the heat treatment step 6, if the material of the molten metal is the aluminum alloy, the heat treatment is the T6 treatment or the T7 treatment and so forth.

With the water-soluble binder, using the polyvinyl alcohol or its derivative, or the starch or its derivative, no unpleasant odor of a gas is generated in the preparing step 1 to stir and prepare the aggregate granular material with the binder and the molding step 2 to mold the core mold.

Also, in the pouring step 4 to pour the molten metal into the molded core mold, neither an unpleasant odor nor an undesirable volatile gas from the core mold is generated, even when the binder is heated by the heat transfer from the molten metal.

As shown as in Fig. 1, the heat treatment step 6 of the casting process of the present invention may be followed by additional steps, if needed. The additional steps include a step 7 of returning the used aggregate granular material (i.e., the core-sand grains) or crushed rocks, a step 8 of milling the crushed rocks, and a step 9 of mechanically recovering the returned sand

grains. The returned and recovered sand grains can be recycled and used for molding a new core mold.

The specified embodiment of the casting process of the present invention will be explained in line with the flowchart of Fig. 1. The descriptions below of the materials are solely for the purpose of exemplifying the embodiment and should not be taken as restricting the invention to these descriptions.

As shown in the following tables, in this embodiment, two mixtures, A and B, of aggregate granular materials are prepared during the preparing step 1.

Table 1

Mixture A of Aggregate Granular Material

Aggregate granular material: Silica sand (Flattery sand) 100wt%
Water-soluble binder: Polyvinyl alcohol (JL-05, made by Japan VAM & Poval Company) 0.2 wt%
Cross-linking agent: Butane-tetra-carboxylic acid (Rikashid BT-W, made by New Japan Chemical Company)

The mixture of 100 wt% aggregate granular material that is composed of the composition as shown in Table 1 and water of 6wt% are mixed, stirred, and kneaded to cause it to foam. A whipped and creamy mixture A of aggregate granular material is thus obtained.

Table 2

Mixture A of Aggregate Granular Material

Aggregate granular material: Silica sand (Flattery sand) 100wt%
Water-soluble binder: Polyvinyl alcohol (JL-05, made by Japan VAM & Poval Company) 0.2 wt%; Starch (Dextrin ND-S, made by Nippon Starch Chemical Company, Japan) 1.0 wt%; Citric acid (made by Fuyo Chemical Industries, Japan) 0.4 wt%

The mixture of 100 wt% dried aggregate granular material that is composed of the composition as shown in Table 2 and water of 6wt% are mixed,

stirred, and kneaded to cause it to foam. A whipped and creamy mixture B of aggregate granular material is thus obtained.

The prior-art shell molding process needs heating elements for the production of the resin-coated sand and needs deodorizing equipment for removing the hazardous gases due to heating the resin. In contrast, the preparing step 1 needs neither a heating element nor deodorizing equipment.

Two whipped and creamy mixtures, A and B, that are prepared in the preparing step 1, are separately pressure-charged into a respective cavity (not shown) in the corresponding metal mold (not shown), which is maintained at a temperature of 250 °C, and held for a period of one minute. The moisture content within the respective mixture is evaporated to harden the mixture such that a respective core mold is removed from a respective cavity of the corresponding metal mold (the molding step 2).

As previously described, the core mold is assembled with the mating mold to form the completed mold (the assembling step 3). In the assembling step 3 of the embodiment, the respective core mold and the corresponding master metal mold of a low-pressure molding machine are assembled to form the completed mold so that it is ready and waiting for the pouring step.

The molten metal is poured into the respective completed mold (the pouring step 4). In the embodiment, a molten metal of an aluminum metal alloy AC4C having a temperature of 720 °C is poured from beneath into the respective completed mold using the low-pressure molding machine (not shown). With the temperature of 720 °C of the molten metal, the binder can be volatilized or dissolved such that the respective core molds can be readily removed from the corresponding cast article in the following step.

The respective core mold is removed from the corresponding cast article during the periods of a cooling process of the cast article after the molten metal is solidified (the removing step 5). The prior-art shell mold process needs a process to apply a greater impact to the core mold to collapse it to remove it from the cast article that has been sufficiently cooled. In contrast, because the method of the present invention employs a collapsible core mold that can be readily collapsed, the core mold does not need either significant cooling nor a following step to apply a high impact force on it to remove it from the cast

article. Accordingly, the core mold can be easily removed from the cast article such as by means of weak shakings, described below. In the removing process 5, the cast article that is composed of the solidified molten metal is removed from the completed mold 10 minutes after the pouring is completed. Immediately after the cast article is removed from the mold, the weak shakings or the impact forces of less than 1MPa at an operating frequency of 20Hz are applied to the cast article having a temperature of 350 °C for less than 20 seconds to remove sand particles such that the core mold is completely removed from the cast article. Alternatively, in an experiment in the removing step 5, the weak shakings or the impact forces of less than 1MPa at an operating frequency of less than 30 Hz are continued in periods of less than 30 seconds, within from 5 to 20 minutes after said molten metal is poured. In this case, the core mold can be also completely removed from the cast article.

The cast article is heat-treated (the heat treatment step 6) after its pouring gate and casting fines are removed. Although in this embodiment the pouring gate and casting fines of the cast article are removed before the heat treatment step, they may be removed after the heat treatment step.

Again, the heat treatment step 6 of this embodiment may be followed by the returning step 7, the milling step 8, and the mechanical recovery step 110, as shown in Fig. 1.

If the master mold is a metal mold, the used aggregate grains or crushed rocks are salvaged or returned from just the core mold and thus the salvaged and recovered aggregate grains may be readily recycled and used for molding a new mold.

Fig. 2 (the prior art) shows a comparative flowchart of the prior-art casting processes based on the shell molding process as disclosed in Japanese Patent Early-Publication No. 5-261478.

The prior-art process of Fig. 2 employs resin-coated sand. Typically, the resin-coated sand is prepared and commercially delivered from a manufacturer that differs from a castings industry maker. Therefore, a step 11 of preparing the coated-sand is typically carried out at a site that differs from casting facilities. This causes difficulties in recycling and using the used resin-coated resin for molding a mold, even if the used resin-coated resin may be

successfully salvaged and recovered. This contrasts with the casting process of the present invention.

With the prior-art process of Fig. 2, the castings industry maker heats the commercially available resin-coated sand to mold a core mold (as shown in a step 12), and assembles it with another mold into a completed mold (as shown in a step 13). Then the molten metal is poured into the completed mold (as shown in a step 14). The core mold is then removed or shaken out from the cast article with a furnace for removing sand (as shown in a step 15). After the cast article is sufficiently cooled (as shown in a step 16) the molded sand should be completely shaken out by using the knockout process (as shown in a step 17). The cast article is then subjected to the heat treatment (as shown in a step 18). During the steps of the knockout process 17, the heat treatment 18, and the following process, the core sand that includes sand clots is returned (as shown in a step 19). The returned sand is milled (as shown in a step 20), roasted (as shown in a step 21), and mechanically recovered (as shown in a step 22) by a company that produces resin-coated sand. Such a company mostly does the production away from the job site of the returning step 19.

Apparently the number of processes in the casting process of the present invention as shown in Fig. 1 is lower than the number of the prior-art processes as shown in Fig. 2. For example, the removing step 5 of the inventive casting process of the present invention can be readily carried out with a means for removing the sand such as a means using weaker shakings, since the inventive casting process employs the collapse-prone core molds. In contrast, the prior-art casting process as shown in Fig. 2 needs the removing step 15 for removing the sand by means of the furnace for removing sand, the cooling step 16 for sufficiently cooling the cast article, and the knockout process 17. The inventive casting process needs no roasting process 21 for returning and recovering the used sand as in the prior-art casting process.

Fig. 3 is a graphic representation of the relationships between the temperatures of the cast article and the periods during the step 5 to remove a completed mold from the cast article and the process 6 to apply the heat treatment to the cast article of the embodiment of the present invention. To compare and contrast the present invention, Fig. 4 is also a graphic

representation similar to Fig. 3, but for the corresponding steps of the prior-art process.

As described above, in the prior-art process there is a sufficient cooling of the cast article (the step 16 of Fig. 2) followed by removing the sand with a knockout process (the step 17 of Fig. 2). The cast article is then re-heated to subject it to the T6 treatment. The prior-art process thus needs the time to cool the cast article, the time to re-heat the cast article to subject it to the heat treatment, and consumes energy.

In the embodiment of the present invention, as shown in Fig. 3, the molten metal having a temperature of 720 °C is poured into the completed mold. The cast article that is composed of the solidified molten metal is then removed from the completed mold followed by the core mold being removed from the cast article. To remove the core mold from the cast article, in the inventive casting process, the cast article needs no greater impact force to be applied to it after it is sufficiently cooled. The cast article thus can be immediately subjected to the heat treatment. This causes a reduction of the time to cool the cast article, the time to re-heat it for the heat treatment, the consumption of energy, and the number of processes. When consuming energy, it is not necessary to cool the cast article at temperatures down to 100 ℃, or even to cool the cast article to a temperature down to 300 ℃.

The forgoing embodiments are just for the purpose of illustration, but are not intended to be any limitation. Accordingly, those skilled in the art could have made various changes and modifications to the above embodiments without departing from the scope of the invention defined by the appended claims.